Module 2: What is Erosion and Why Does Erosion and Sediment Control Matter

Module 2 Objectives

After completing this module, you will be able to:

- Define what Erosion and Sediment Control is
- List and explain the two sources of erosion, the five types of erosion and the four contributing factors
- Describe why we need erosion and sediment control including environmental and socioeconomic reasons

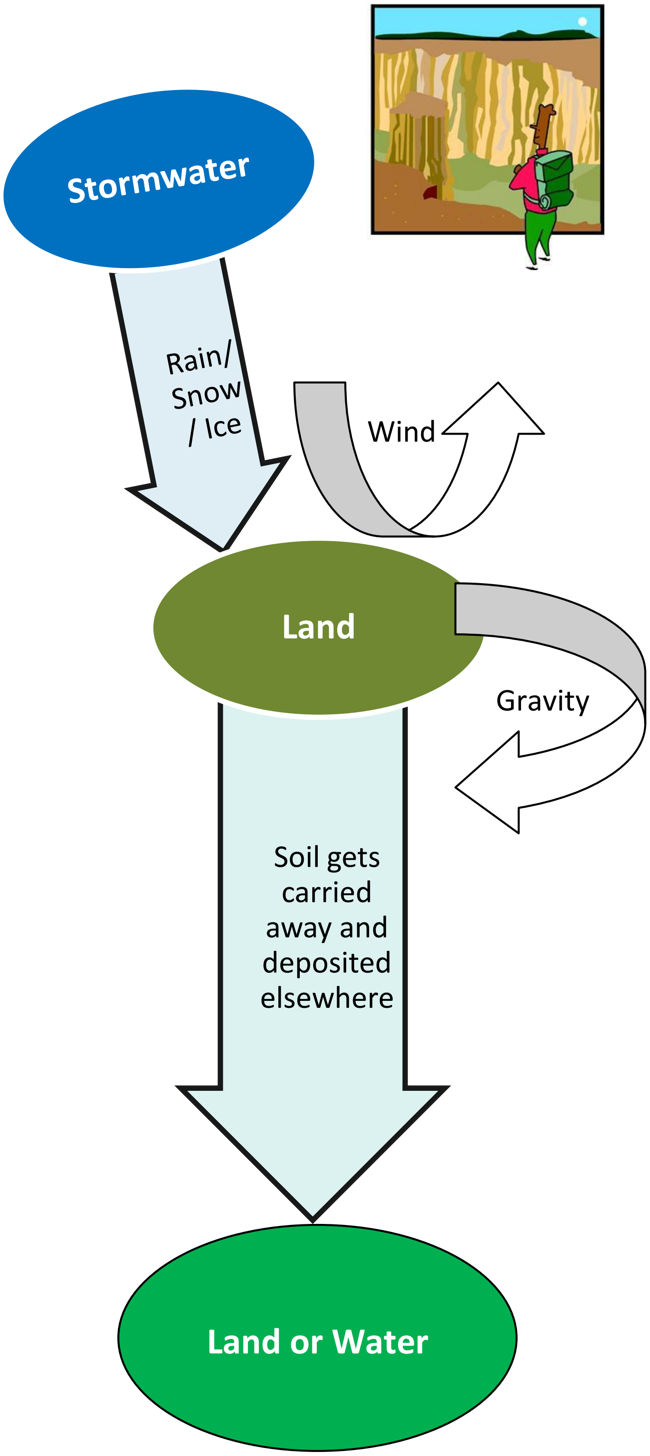
Module 2 Content

2a. Introduction

This module provides the scientific foundation for understanding erosion and sediment control (ESC) in Virginia, and the consequences of ineffective control on our natural waterways. This module defines erosion and sedimentation and relates its impact to the environment and society as a whole. It also provides economic reasons for ESC.

Figure 1. Downstream example of poor erosion and sediment control upgrade

2b. Erosion Defined



Soil erosion is defined as the *removal of the land surface by erosive forces such as water, wind, ice, and/or gravity.*

Erosion processes carry away soils from one site and deposits the soil on another site. Erosion is an important contributor to landscape formation by wearing away mountains; filling valleys; and creating sandbars, islands and coastal planes. Erosion is a natural process, but in many places it is increased by human land uses that disturb the soil.

Figure 2. Bryce Canyon (UT)

Two Sources

- Geologic (30%)
- Accelerated (70%)

Five Stages

- Raindrop (90%)
- Sheet
- Rill
- Gully
- Channel

Four Contributing Factors

- Climate
- Soils
- Slope
- Ground cover

2c. Sources of Sediment

Erosion can be divided into geologic (natural) and accelerated (human induced) erosion. In Virginia, our primary concern is with accelerated erosion or erosion arising from land-disturbing activities resulting in the detachment and transportation of soil onto downgradient properties and/or waterways. Continued population expansion in the Commonwealth of Virginia is imposing new stresses on the state's watersheds, resulting in undesirable impacts of sediment inputs caused by erosion and on the quantity and timing of water flows.

Geologic Erosion (erosion resulting from the detachment and transportation of soil by water, wind, ice, and gravity) is a natural process that has been occurring since the beginning of time. Mountain ranges have eroded down, leaving sediment deposits several miles thick. In fact, Virginia has been greatly affected by erosion: in geologic time the Appalachian Mountains used to be the tallest mountains in the world, taller than today's Himalayan Mountains. Over time, these mountains eroded away and the sediments were carried to the oceans by the rivers coming from the mountains. As a result, Virginia's coastal plains have sediment deposits that are in places more than 600 feet deep. The Grand Canyon is another spectacular example of natural or geologic erosion.

A slowly moving process, geologic erosion accounts for **thirty percent (30%)** of the total sediment deposited in the United States.

Accelerated Erosion (erosion resulting from human land-disturbing activity resulting in the detachment and transportation of soil onto adjacent properties and/or waterways) occurs at a much faster pace than geologic erosion. In the United States, accelerated erosion dates back to the first European settlers who cleared slopes and fields to plant crops during the pre-revolutionary days. Accelerated erosion accounts for **seventy percent (70%)** of the sediment deposited in the United States. **Minimizing the impact of accelerated erosion is the primary objective of Virginia's Erosion and Sediment Control Program.**

Figure 3. Agriculture, one of the contributors to accelerated erosion

Geologic erosion accounts for 30% of total sediment production, accelerated erosion accounts for 70%

Major Industries Contributing to Accelerated Erosion:

Agriculture, building construction, surface mining, and forestry are the major contributors of accelerated erosion. Agricultural activities account for 72% of the total sediment generated by accelerated erosion in Virginia. Sedimentation from building construction accounts for most of the remaining 28%.

However, on a per acre basis, when comparing a construction site with and agriculture field of the same size, construction sites contribute ten to twenty times higher sediment rates than those found from cropland or naturally vegetated areas. This trend is illustrated in Table 2-1 which shows the yearly sediment rates for the four major land uses contributing to accelerated erosion.

On a per acre basis construction accounts for 10 times more sediment production than agriculture

TABLE 2-1.
SEDIMENT TONNAGE PER SQUARE MILE BY YEAR

Land Use	Sediment production	
	(tons/mile^2/year)	(tons/acre/year)
Forest	24	0.04
Grassland	240	0.38
Cropland	4,800	7.5
Construction	48,000	75

Source: Environmental Protection Agency study (EPA 430/9-73-014)

The potential for erosion is not necessarily reduced after construction is complete. Increased stormwater runoff from impervious surfaces such as roofs and parking lots has the potential for causing severe channel damage to streams. Streams in previous stable condition experience increased sediment and nutrient loads which lead to further degradation of the stream itself and downstream receiving waters.

2d. Five Stages of Water Erosion

As mentioned in Section 2c, the major agents of erosion are water, ice, wind and gravity. While the first three factors are considered to be climatic factors, gravity is a physical factor responsible for movement of terrestrial bodies or particles to the lowest elevations in a landscape. In a general sense, climate is the most significant agent in the erosion process, and in Virginia our concern is focused primarily on water as an erosive force. Water initially impacts the landscape as precipitation (mostly through the impact of raindrops). Runoff follows a rainfall event when the rate of rainfall exceeds the water absorption capacity of the soil. Although temperature and snow cover are significant factors in Virginia, the impact of rain and the resulting water that moves across a newly developed site (stormwater runoff) is by far the most significant and damaging agent in the erosion process.

Rainfall erosion is a five-stage process including *Raindrop Impact, Sheet Erosion, Rill Erosion, Gully Erosion,* and *Channel Erosion*.

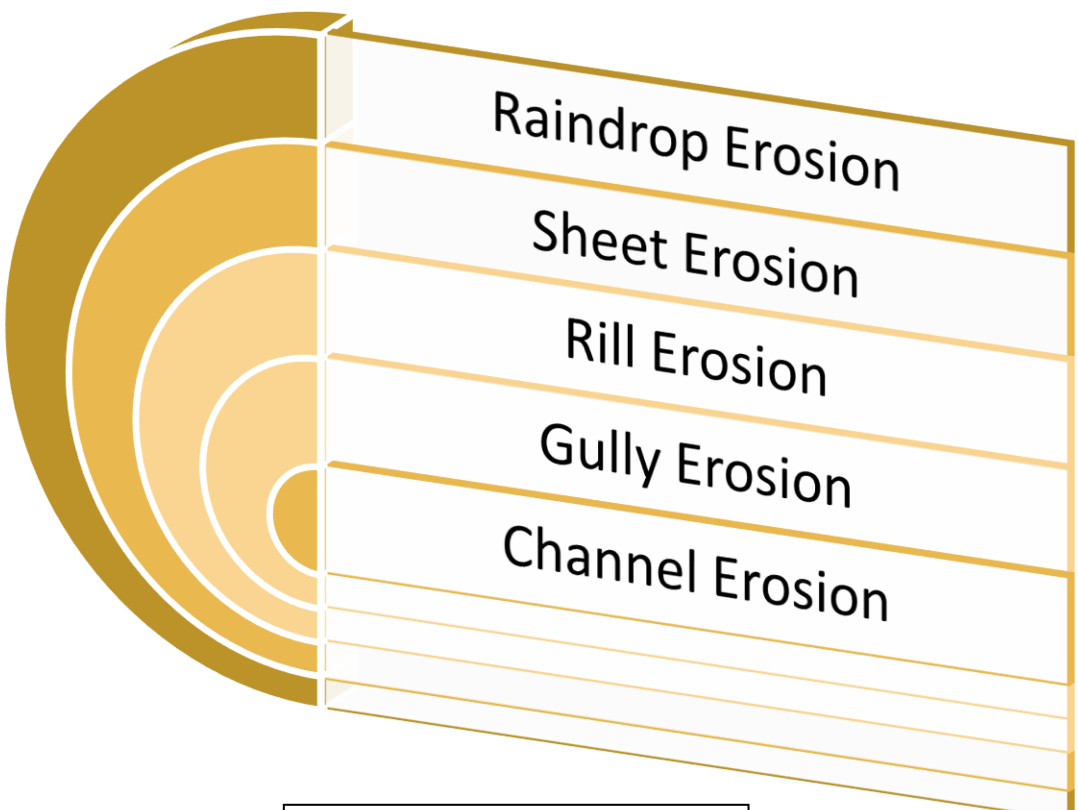


Figure 4. The five stages of water

Raindrop Impact *is the first effect of a rainstorm on the soil dislodging soil particles and splashing them into the air*. These detached particles can then easily be picked up by water flowing over a site and become sheet erosion.

Figure 5. Raindrops impact the soil as little bombs.

Figure 6. Sheet erosion

Sheet Erosion *is erosion caused by a shallow sheet of rainwater that runs across the land*. These very shallow, moving sheets of water seldom detach soil but rather picks up and transports soil particles already detached by raindrop impact, splash or by soil disturbances such as grading, cut and fill operations or digging. Sheet erosion rarely moves for more than a few feet before concentrating in surface irregularities.

Rill Erosion *develops as the shallow (sheet) flow begins to concentrate in low spots*. As the flow changes from sheet flow to deeper flow in these low areas, the velocity and turbulence increase. The energy of this concentrated flow detaches and transports soil material, cutting tiny channels or rills that are only a few inches deep. At this stage, hand tools or other surface treatments will easily repair erosion damage.

Figure 7. Rill erosion

Gully Erosion *occurs when rills converge to form larger channels or gullies*. The major difference between gully and rill erosion is size. Gullies are too large to be restored with conventional tillage equipment and usually require heavy equipment to repair.

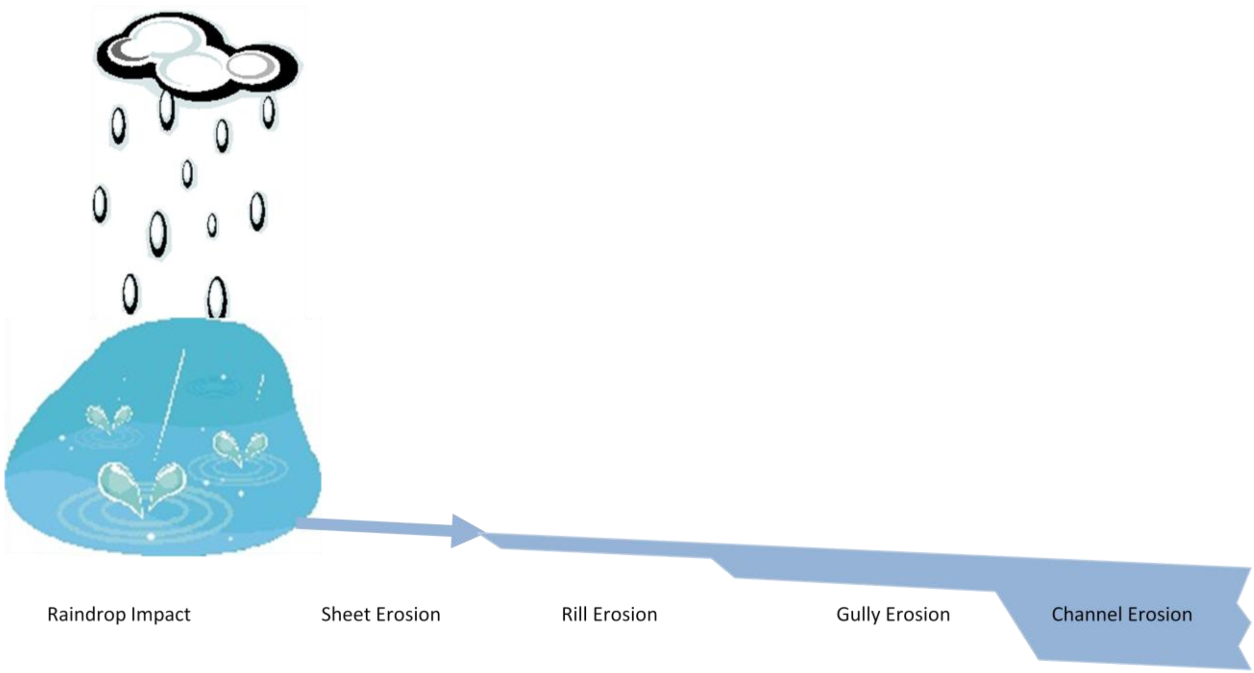
Figure 8. Gully erosion

Figure 9. Channel erosion

Channel Erosion *can occur in two ways:*

(1) When gullies are not repaired in time and large volumes of water increase the size of the gully, or

(2) In existing stream when the volume and velocity of flow destroys the structural integrity of stream beds and banks.



Raindrop Impact:

Of the five types of erosion, **Raindrop Erosion** is the most significant when it comes to the erosion process. The action of falling rain on disturbed or denuded soil is responsible for 90% or more of total soil erosion. Raindrop impact produces two damaging effects:

- The detachment and transportation of surface soil, and
- Puddling or sealing of the soil surface.

Raindrop impact is responsible for 90% of the soil loss on denuded soil

Neutralizing these two effects is the first and most important part of erosion control.

How can rainfall be responsible for so much damage?

Observation of intense rain on bare soil attests to the destructive power of Raindrop Impact. Raindrops hit the surface like tiny bombs, shattering soil granules and splashing the detached material back and forth. The erosive capacity of rainfall comes from the energy of its motion, or *kinetic energy*. The magnitude of this energy is dependent on the amount and intensity of rainfall, raindrop diameter, and raindrop velocity. Raindrop size ranges from the finest mist to drops that are 1/3 inch or nearly 8 millimeters in diameter. All rain events will contain drops of various sizes. An intense rain has a much higher proportion of large drops than a light rain.

Raindrop velocity is closely tied to drop size. Fine mists with droplets of about 1/100 inch (.25 mm) in diameter fall at a rate of about 1 inch per second (25 mm per second). Conversely, large drops may attain a velocity of 30 feet per second (10 meters per second). The damaging effects from rain falling as large drops in an intense thunderstorm has many times more erosive energy than rain falling as a fine drizzle over a longer period of time. In an intense rain event splashed soil particles may be moved more than two feet (61 cm) high and five feet (150 cm) horizontally. This can be frequently observed on fences, on the walls or foundations of buildings where splashed soil particles can be seen clinging to fences or the foundation of buildings that are adjacent to bare soil. Particles can be seen on stems and leaves of plants that are growing in a partially vegetated field. Pedestals of soil, capped with protective stones, can be seen where raindrops splash carried away unprotected material.

Figure 10. These rocks protected the soil from raindrop impact, in places where there were no rocks the soil was loosened and washed away.

On level surfaces, the horizontal and vertical effects of splashed soil are self- cancelling. However, on sloping land, the net movement is downhill. For example, on a 10% slope, 75% of the soil movement is down-slope.

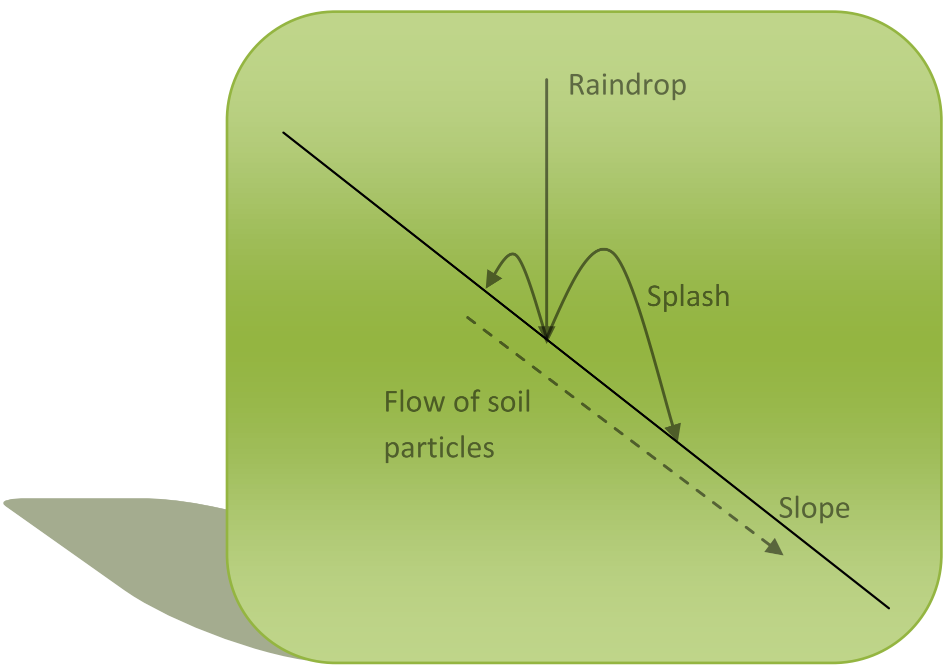


Figure 11. On slopes raindrop impact moves the majority of the soil down the slope

Another damaging effect of raindrops is the *compacting, puddling, and sealing of the soil surface*. Repeated strikes churn the surface into a slurry. This viscous mass effectively seals the pore spaces in the soil preventing water infiltration. As they continue to pound the land, raindrops will also compact the bare soil, forming an almost complete seal. Even on coarse sandy soil, this action reduces the infiltration of water into the soil and leads to increase runoff and erosion.

Figure 12. Sediment-laden water and raindrop impact are slowly sealing the soil in this agricultural field

As mentioned above, the erosive impact of raindrops is influenced by the size of the drops and the speed by which they hit the soil. Drop size and speed are often seasonally influenced. In Virginia, the most erosive rains are concentrated during the months of June through September when rainfall events occur as thunderstorms and tropical systems. This is also the period when land-disturbance is most active. Precipitation in the winter generally falls as a finer mist.

Table 2-2 below indicates some significant differences between storms occurring during the spring and summer and those occurring during the fall and winter.

TABLE 2-2
PRECIPITATION CHARACTERISTICS BY SEASONS

Characteristics	Sept. through April	May through Aug.
Form	Rain and/or Snow	Rain
Intensity	Low	High
Drop Size	Small	Large
Duration of Storm	Long	Short
Area of Storm	Large	Large or Small

Runoff:

Runoff *occurs when the rate of rainfall exceeds the infiltration capacity of the soil*. Runoff on unprotected soil begins a few minutes after the start of rainfall. While raindrops have a lot of (kinetic) energy when they hit the soil, water collecting on the land has no kinetic energy. Water on the soil gains energy from its movement as it begins to run down slopes as runoff.

Runoff *occurs when the rate of rainfall exceeds the soil's infiltration capacity*.

In this early stage, the major potential for damage caused by runoff is the ability of stormwater to transport soil particles that are dislodged by the raindrop splash effect, by grading, clearing, vehicular travel and other development activities. This is why it is so important to maintain the vegetation as long as possible on a development site and incorporate phasing within a development project. It is also the reason why it is important to establish temporary or permanent cover (mulch or vegetation) on a site as soon as possible.

The amount of runoff depends upon:

- The amount and intensity of the rainfall, and
- The character of the soil surface impacted by rainfall.

Runoff initially presents itself as **Sheet Flow**, a shallow layer of water flowing more or less uniformly over the land and causing Sheet Erosion. Sheet Erosion primarily refers to the transport of soil particles that have already been detached and suspended by raindrop impact. Runoff in the form of sheet flow occurs on all land surfaces except in rills and gullies. Total soil loss by sheet flow may be large, although it is difficult to observe.

Sheet Erosion can very effectively transport the particles that are kept in suspension by the action of falling raindrops on an area. It has been observed that muddy water flowing across a parking lot leaves a deposit of mud under each car where the sheet flow is not stirred up by falling raindrops. Out in the open, raindrops continuously keep the finely textured sediment particles in suspension, and allow for the continued transport across the unprotected surface, whereas these [articles settle out on the ground underneath the cars where this mixing is prevented.

Sheet flow seldom detaches soil particles

Channelized Flow starts when sheet flow starts to concentrate as a result of irregularities in the soil surface such as low spots, depressions, rocks, plant stems, and roots. As the volume of water in these channels increases, the velocity and turbulence also increases. Runoff concentrated in tiny rills may then combine into larger channels, acquiring more energy to detach and to transport soil particles.

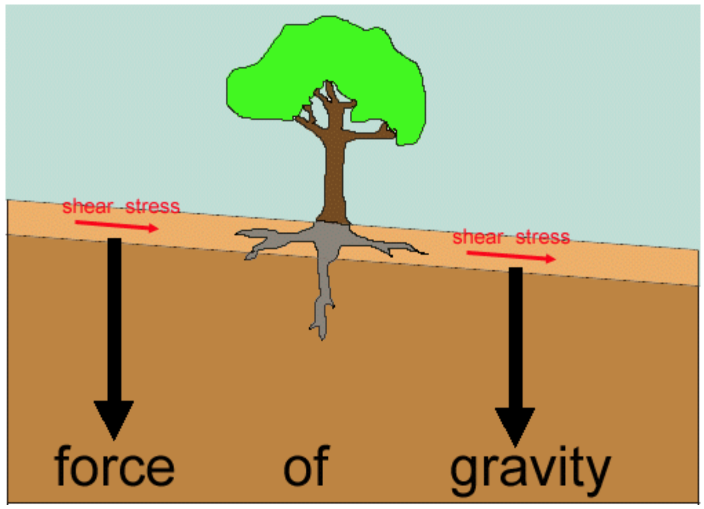


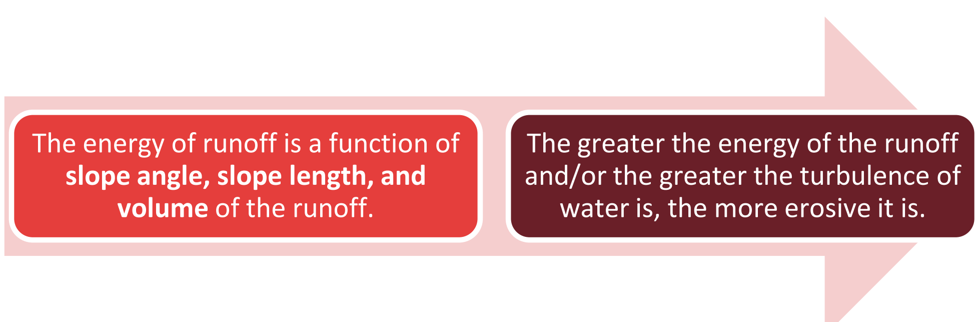
Figure 13. The combined effect of water, suspended sediment and its abrasive effect, and gravity is also known as sheer stress

The rolling, lifting, and abrasive action of concentrated/channelized flow on the land surface results in soil detachment and leads to rill and gully erosion as discussed earlier. At first, the force of channelized flow is horizontal, in the direction of the water flow. When the velocity and turbulence of channelized flow increases, vertical currents and eddies develop, dislodging, suspending and transporting soil particles. These entrained soil particles strike and abrade soil surfaces and channel beds very much like sandpaper. More soil particles detach and are mobilized. This is the detachment by *abrasive action*. The turbulent flow of sediment laden water will start scouring the sides of the rills, gullies and channels. More soils particles will become suspended in the flowing water increasing further its abrasive force. The amount and abrasiveness of the particles suspended and transported by the flow determines the amount of additional sediment detached by abrasion.

In summary, the erosive capacity of flowing water is based on its

- velocity,
- turbulence,
- amount and type of abrasive material conveyed by the flow,
- Surface or channel roughness, and
- slope gradient.

As slope length increases, the depth of runoff increases and hence the velocity also increases.



2e. Four Factors Influencing Erodibility

As we have seen previously, runoff starts when the soils capacity to absorb water is exceeded. Examples of when this happens include:

i. A site gets more precipitation than it can handle.
ii. Soil is frozen
iii. Soil has a low infiltration rate or high runoff potential
iv. A site has steep slopes
v. Slopes on a site are smooth
vi. Groundcover is sparse or non-existent , or
vii. A combination of all these factors

Erodibility = the vulnerability of a material to erosion

These cases can all be brought back to the four factors that influence erosion:

1. Climate
2. Soils
3. Topography, and
4. Groundcover

While these factors are often interrelated, they need to be discussed individually.

Climatic Factors influencing erosion include precipitation type (rain/snow), rainfall intensity and raindrop size; snow melt; temperature extremes (freezing/excessive heat). In a previous section we discussed raindrop impact. As we saw there, raindrops are approximately responsible for 90% of the erosion that occurs on a site. In that section we also saw that summer storms are generally more erodible (Table 2.2). In discussing precipitation (rainfall or snowfall) we often refer to (1) amount and (2) intensity. A 2-inch precipitation event in the winter is likely very different than a 2-inch precipitation event in the summer. Winter rains are often part of a frontal passage; they have smaller drops and might last hours. Summer rains are usually associated with thunderstorms and the same 2 inches of rain could fall in a matter of minutes.

Rainfall (precipitation) intensity equals the amount of rain that falls over a certain time period (i.e. 2 inches/hour or 3.5 inches in 24 hours)

Temperature can also be an important factor. Freezing temperatures in winter can destroy the soil structure and destabilize the soil when the water in the soil expands and soil particle lose the ability to adhere to each other. The loose particles can then be picked up as sediment in the melting water and transported from the site. Warm temperatures can bake the soil, which also destroys the structure of the soil. In addition, hot temperatures and wet soils

Soil Structure: the arrangement of soil particles in various aggregates differing in shape, size, stability, and degree of adhesion to one another

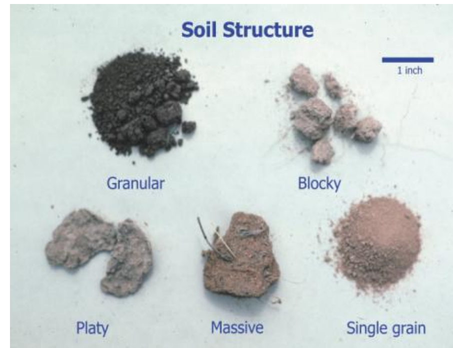


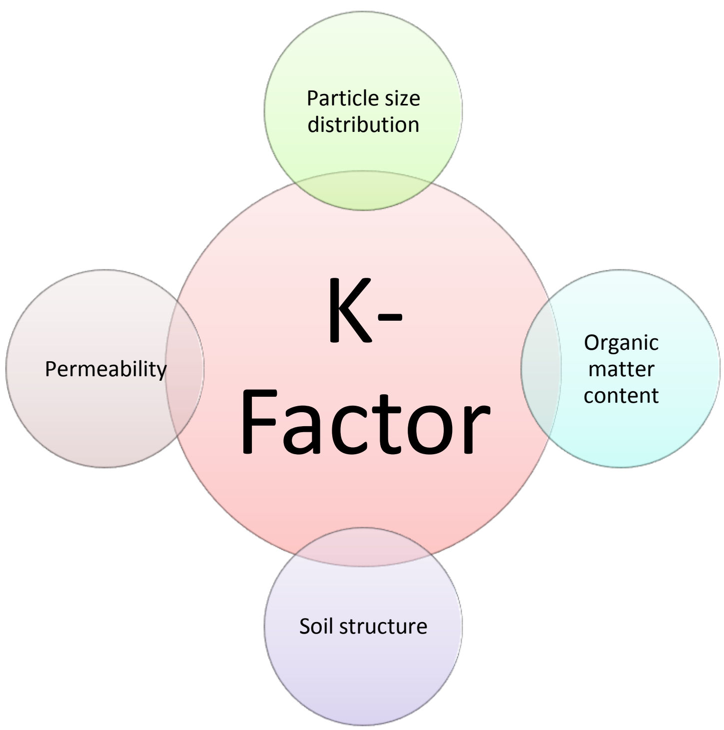
Figure 14. Different soil structures:

can lead to excessive crusting of the soil which results in a host of issues including poor infiltration, increased runoff and poor germination of seeds (due to soil moisture loss and the inability of germinating seeds to penetrate the crust). As we will see later, some of these issues can be alleviated by the use of mulch.

Soil Properties are also important in factors when looking at the erodibility of a site. As mentioned above, structure or the way soil particles adhere to each other is an important factor. Additional properties include soil texture (or the size of the particles in the soil), bulk density (or how tightly those particles are packed together), the percent organic matter, infiltration rate (the speed by which water enters the soil) and permeability rate (the speed by which water moves through the soil).

Even with similar climatic, topographic and vegetative conditions, different soils may erode at different rates. This difference in erosion rates may be tenfold, and is caused by differences in soil characteristics. The susceptibility of a particular soil to erosion *is called its erodibility factor or "K" factor*. In addition to susceptibility of the soil to erosion, the soil erodibility factor (K) represents the rate of runoff.

Soil properties used to develop a K factor for soils include:



Particle size distribution or the composition of the soil in its three components sand, silt and clay influence the *infiltration rate*, or the rate at which waters enters the soil; and *permeability* or the rate at which water will move through the soil. Organic matter influences characteristics such as *cohesiveness, structure and permeability* of the soil. Soil structure is determined by how individual soil particles clump or bind together and aggregate, and therefore, the arrangement of soil pores between them. Soil structure has a major influence on water and air movement, biological activity, root growth and seedling emergence (see Figure 15).

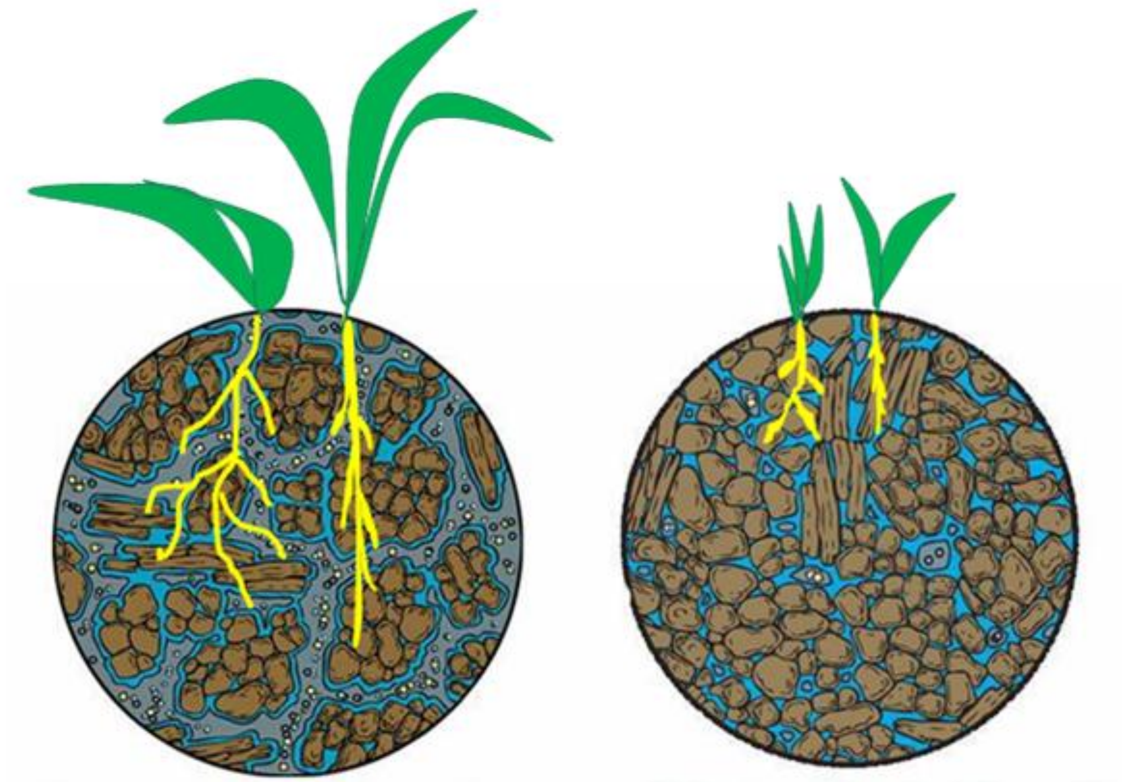


Figure 15. Relationship between bulk density and permeability of soil and its reflection on plant health

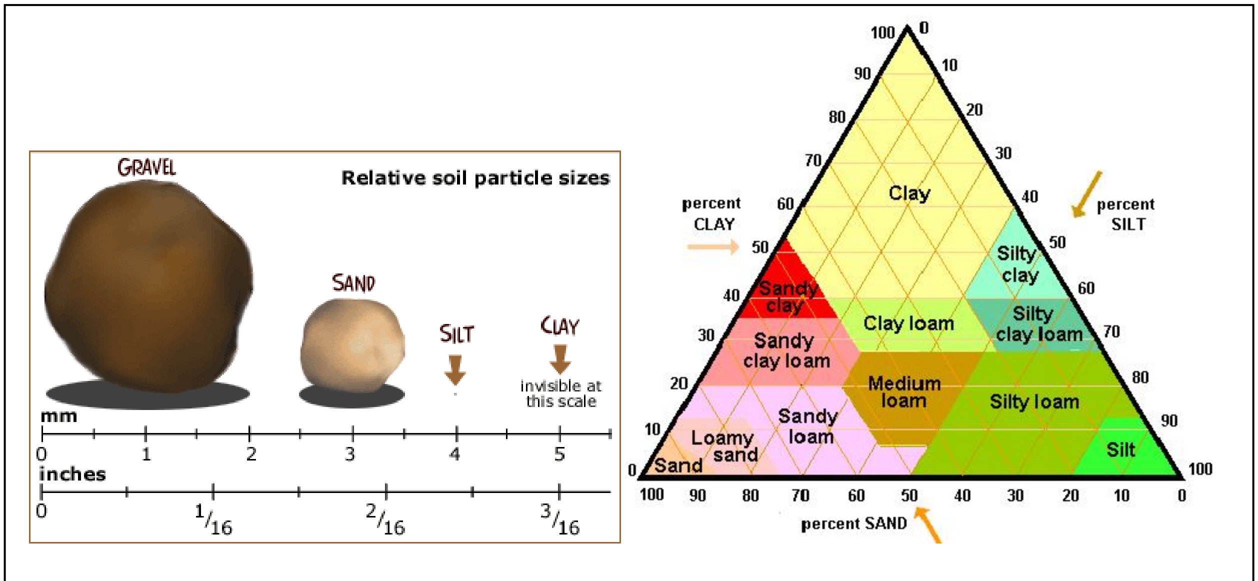


Figure 16. Soils are made up of different in soil particle sizes (left), and these particles can be found in various combinations in the different soil types.

Erodibility is highest in soils with increased silt particles (.002 to .05mm) and very fine sand (.05 to 0.1mm) content; and lower with larger sand particles (0.1 to 2.0mm), clay particles (less than or equal to .002mm), and organic matter content (Figure 16). Soils with high clay content are generally more resistant to detachment, although once detached, the clay particles are easily transported. Clay soils also usually have poor infiltration, which will increase runoff. Increased organic matter reduces erodibility by:

- Serving as an adhesive to hold particles together, and
- Improving the permeability and stability of the soil structure.

Soil erodibility was investigated intensively to develop a widely used mathematical model: the *Universal Soil Loss Equation* (USLE). This equation describes long-term average soil losses expected from sheet and rill erosion for agricultural land uses and illustrates how the implementation of erosion and sediment control measures may reduce the potential for erosion. This method of describing soil loss is a good indicator of the potential for erosion problems based on soil properties. The Universal Soil Loss Equation does not provide an accurate means for estimating sediment yield (actual soil lost from a given area). In the development of this equation, several of the soil factors discussed above were used.

Universal Soil Loss Equation:

$$A = RKLSCP$$

where:

A = average annual soil loss in t/a (tons per acre)
LS = topographic factor (L = slope length, S = slope grade)
C = cropping factor
R = rainfall index
K = soil erodibility factor
P = conservation practice (i.e., BMP) factor

The Soil Erodibility (K) Factor

For the plan preparer/reviewer, job superintendent and inspector who are likely to be laymen in the field of soil science, the K factor is a good indicator of a soil's susceptibility to erosion. The K factor of a soil can be found in various sources, including a county soil survey, on line at the web soil survey (http://websoilsurvey. nrcs.usda.gov/app/HomePage.htm), and in Appendix 6C of the 1992 Virginia Erosion and Sediment Control Handbook.

K factors can be grouped into three general ranges:

0.23 and lower	-	Low erodibility
0.24 to 0.36	-	Moderate erodibility
0.37 and higher	-	High erodibility

The higher the K factor value, the more susceptible the soil is to erosion.

It is recommended that a soil inventory be conducted on a site before beginning land-disturbance in order to identify areas with highly erodible soils. Assistance in soil identification is available from the local USDA-Natural Resources Conservation Service office, Soil and Water Conservation District, or Cooperative Extension Office. Soil maps can be viewed on NRCS' web soil survey site. Below are some resources to get soil information.

http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm

http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/contact/local/

http://www.vaswcd.org/

http://www.ext.vt.edu/offices/index.html

Topographic Features that influence site erodibility include *slope grade, slope length, slope shape and slope orientation.*

Slope steepness or grade influences erosion in several ways. Physics and hydrologic principles teach us that water will flow faster with the increased length and angle of a slope. Moreover, there is more “splash effect” on steeper slopes (Figure 11, page 2-11). These principles are the reason for the grouping of slope gradient into three general ranges of soil erodibility (Table 2.3).

TABLE 2.3.
RELATION BETWEEN SLOPE GRADIENT AND EROSION HAZARD

Slope gradient	Erosion hazard
0-7%	Low
7-15%	Moderate
15% & over	High

In the case of Erosion and Sediment Control, *slope length is defined as the distance from the point where overland flow begins to the point where it enters a well-defined channel, waterway or the point where deposition may occur because of a decrease in slope gradient*. The same principles tell us that increasing slope length will increase the water accumulated in the runoff. Therefore, using these principles, there will be a point on a slope where water volume and velocity will start to result in rill and gully formation (where the slope becomes *critical*). Table 2.4 provides the critical slope length for different slope gradient ranges.

TABLE 2.4.
SLOPE GRADIENT AND LENGTH COMBINATIONS AT WHICH THE EROSION HAZARD WILL BECOME CRITICAL

Slope gradient	Slope length
0-7%	300 feet (100 meters)
7-15%	150 feet (50 meters)
15% & over	75 feet (25 meters)

Slope shape also impacts erosion potential:

- *Convex slopes (are slopes that are steeper at the lower end).*
- *Concave slopes (are slopes which flatten at the lower end).*

Erosion will be more on convex and less on concave slopes than what would be expected if the effect is calculated on the basis of an average grade.

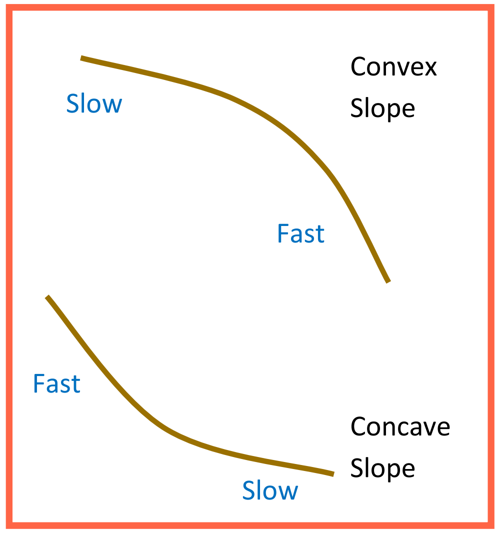


Figure 17. Slope shape impacts runoff speed and erodibility of the slope

Slope orientation or aspect also affects erosion. South and southwest facing slopes are usually warmer and drier because of sun exposure and exposure to warmer winds. Therefore, the vegetation on these slopes may be sparser, and establishment of new vegetation on south and southwest facing slopes is usually more difficult than establishing vegetation on northern slopes. Conversely, northern slopes are cooler, less exposed to the sun, and usually moister; it has therefore different challenges in establishing vegetation on northern slopes. This may also dictate species choice for final stabilization after a project is completed.

Ground cover is the last of the four major factors influencing erosion. As was discussed earlier in this chapter; the size of raindrops and the speed by which they hit the soil are among the most important factors influencing erosion. Ground cover such as vegetation or mulches slow down the speed of raindrops by intercepting them on leaves, branches, and stalks, thus breaking up raindrops into smaller drops. Research has shown that erosion potential is directly proportional to the amount of bare soil exposed to raindrop impact. Therefore, surface cover is the most important factor for controlling erosion. Vegetative cover provides the best protection; however, the use of any surface cover material, including vegetation and mulches, offers an excellent range of control options.

Research has shown that the amount of erosion depends on how much of the land surface is exposed to erosive forces such as raindrop impact and scouring. Vegetation of the right type and density provides excellent protection for soil that is exposed to the unimpeded impact of falling rain. Moreover, roots and litter also resist scouring. In a controlled experiment involving identically sized plots seeded at significantly differing density rates (i.e. 9,000 plants per acre on one plot & 14,500 plants per acre on the other plot), soil loss over a 10-year period was four times greater on the less densely populated plot. In the above study, soil exposure was measured from aerial photographs.

Table 2-5 below provides the protection and percent effectiveness of various grasses and additional ground covers when compared to the erosion rate for an identical plot of bare soil.

TABLE 2.5.
EFFECTIVENESS OF VARIOUS GROUND COVERS IN PREVENTING SOIL EROSION

Type of Ground Cover	Percent Reduction
Permanent grass	99
Perennial ryegrass	95
Annual ryegrass	90
Small grains	95
Millet or Sudan grass	65
Field bromegrass	97
Grass sod	99
Hay or straw (@2 tons/acre)	98

(this table compares fully established stands of groundcover with bare soil)

Although Table 2.5 does not contain values for woodchips, wood cellulose fiber, and similar mulching materials, when applied according to specifications these controls are usually 90% effective (application rate: Woodchips 6 tons/acre, and Wood cellulose fiber $1^{3}/_{4}$ tons/acre).

The discussions in this section thus far have emphasized the tremendous reduction of erosive soil loss by maintaining vegetated areas on a project as long as possible, or by stabilizing a site with some form of surface cover including vegetation and mulches. Vegetation not only minimizes splash erosion, but also prevents puddling and sealing of the soil surface. In addition, a good vegetative cover (or mulch) significantly reduces runoff. This was shown in studies on plots composed of different soil types demonstrate that protected plots offer higher *water intake rates* than the water intake rates found on bare soil even when exposed to high rates of sustained rain. Similarly, *water infiltration rates* on plots protected by vegetative cover are significantly higher than the rates measured for unprotected plots subjected to identical rainfall conditions. This result was similarly observed on plots of dune sand that were protected and unprotected.

One additional value of vegetation is its use as a protective lining along shallow waterways and channels, where its use can reduce the flow velocity near the bed of the channel. Vegetation with a dense uniform growth near the soil surface and a strong fibrous root system is most effective in reducing erosion. Good uniform stands of sod-forming grasses meet these requirements by providing good surface cover even after mowing. With good management these grasses will retain their density indefinitely. Additionally, the roots of vegetation used in waterway improve soil structure and increase organic matter content. In some instances, a solid root structure minimizes erosion to the banks and bed of the channel, providing some protection against the mud flows which occur on thawed, saturated surface layers above frozen soil.

2f. Why Erosion Matters

Erosion is a natural process, and in the previous section we have seen that there are two types of erosion: geologic or natural erosion and accelerated or man-made erosion. Over geologic time the Appalachian Mountains eroded away and the sediment was deposited off the coast, forming the coastal plain.

Geologic Erosion – 30%
Accelerated Erosion – 70%

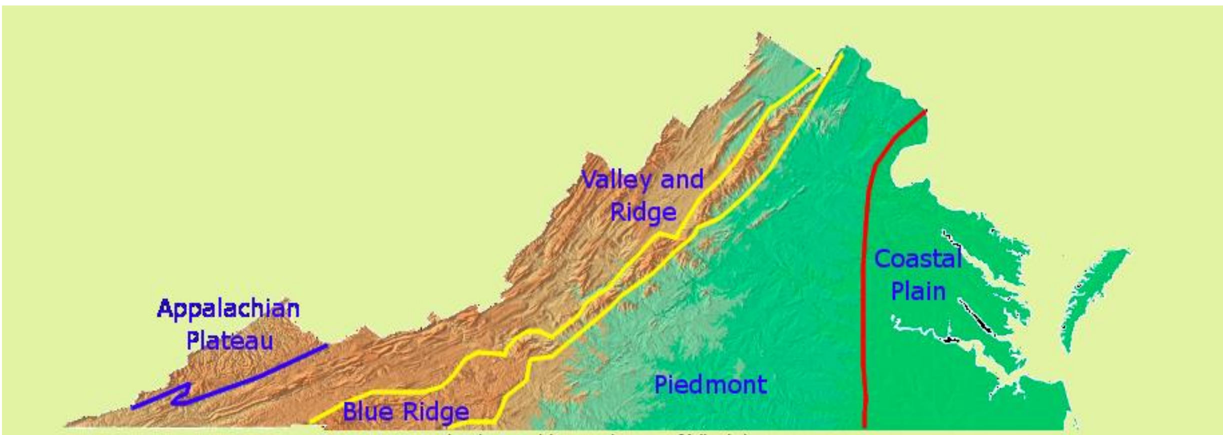


Figure 18. The physiographic provinces of Virginia

While geologic erosion has stayed relatively steady over the past thousand years, accelerated erosion has gradually increased with the growing human population and the resulting increasing pressure on the land. The soil particles loosened up by erosion are called sediment. These soil particles may have heavy metals and other contaminants attached to them. Some of the negative impacts of sediment released into the environment are shown as part of Figures 19 and 20.

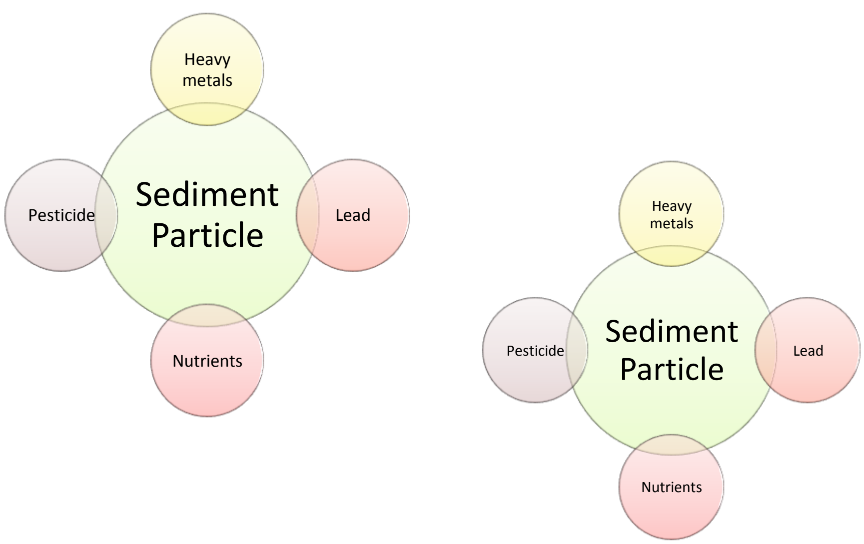


Figure 19. Sediment particles have all kinds of elements, metals and other contaminants stuck on them which can be released into the environment.

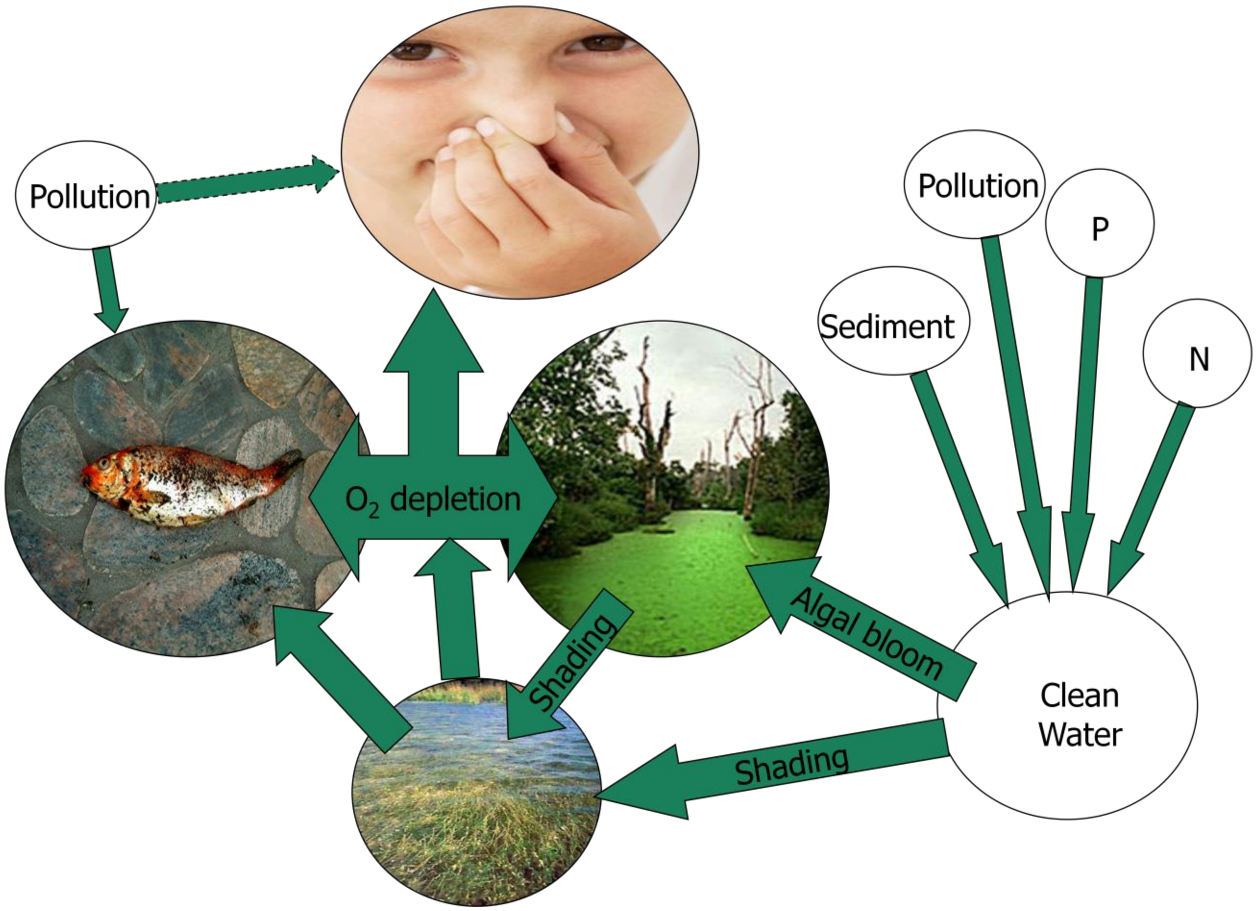


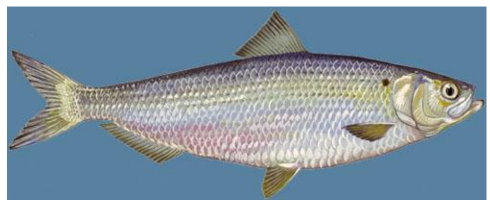
Figure 20. When sediment and associated/attached contaminants and nutrients (**P**hosphorus and **N**itrogen) enters waterways a cascade of issues can occur:

(1) Sediment shades the bottom of the waterway and weakens or kills the aquatic vegetation, which oxygenate the water and serve as cover for young fish and other aquatic organisms;
(2) Nutrients stimulate algae to grow resulting in algal blooms. This algal proliferation shades native aquatic vegetation and decaying algae and native vegetation depletes oxygen in the water;
(3) Sediment and contaminants in the water plugs gills of fish and other aquatic organisms thus weakening and/or killing them;
(4) Sediment settles in waterways and smothers spawning beds, oyster reefs, crab habitat, etc;
(5) Stocks of fish, oysters and crabs decline and reduce the income of commercial watermen and sports fishermen, , thereby hurting the economy of the region; and
(6) Shipping lanes, reservoirs, harbors, marinas, and other waterways may require dredging, at considerable cost (Tables 2.6 and 2.7).

The financial loss to the commercial water men and the commercial sports fishing industry whether it is in the bay, its tributaries, lakes, or mountain streams as a result of erosion and sedimentation cannot be estimated.

Few examples of Anadromous fish of Virginia: Fish that live in salt water but migrate to fresh water (up rivers) to spawn (source VDGIF). They and many other fish need clean water to spawn. A lot of fish species will also will need a gravel bed to lay their eggs in, while immature fish may need hiding places such as aquatic vegetation to stay out of the way of predators.

American shad



Blueback herring

Alewife

Striped bass

Other species such as blue crab, oysters and trout are also dependent on clean water with low turbidity. While small crabs also hide in aquatic vegetation, oysters need a hard surface to grow on and will choke in mud and muddy water.

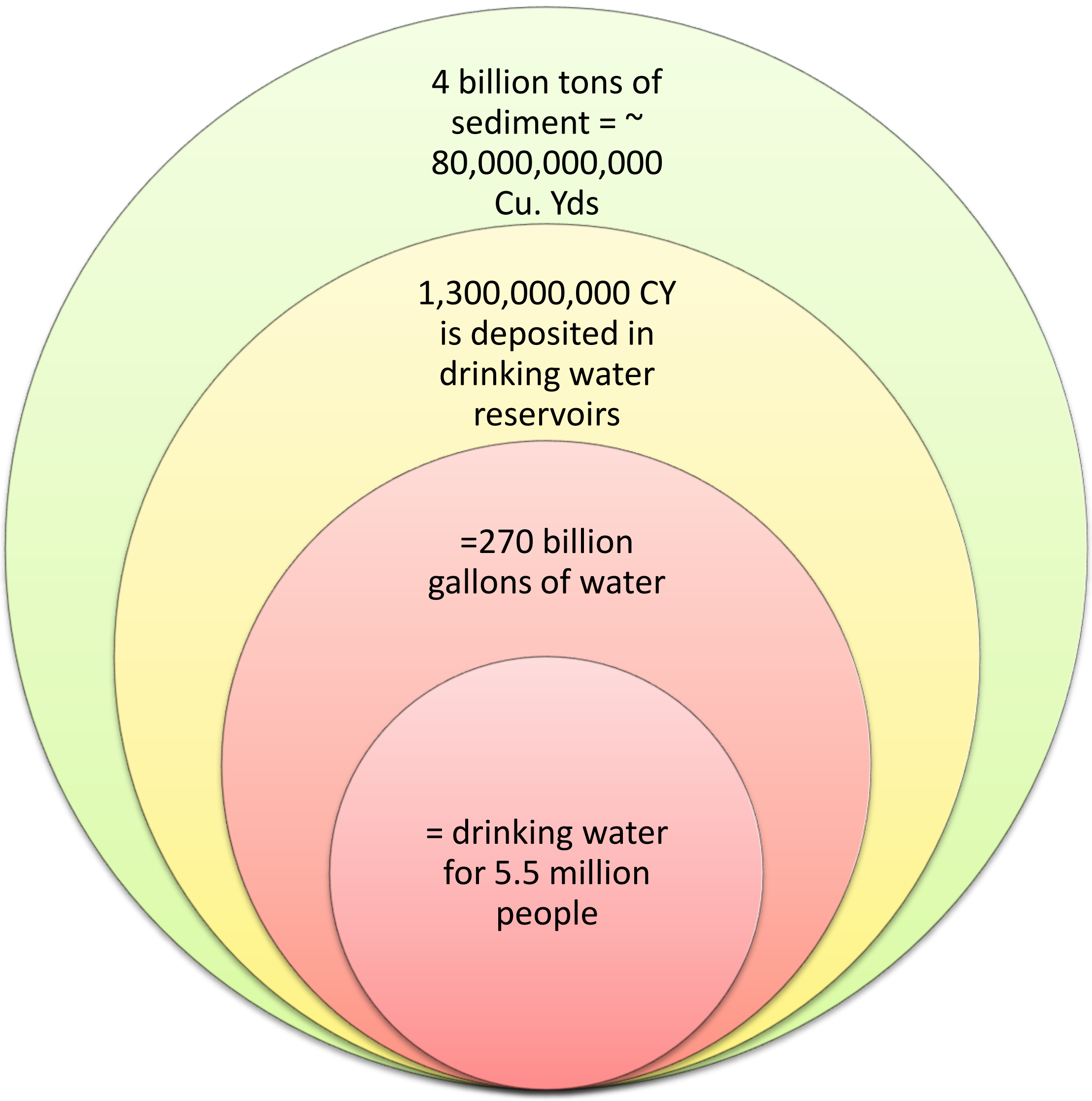
Blue crab

Oyster

Trout

Quantifying Erosion and Sediment Control

It has been estimated that the total sediment production in the U.S. is 4 billion (4,000,000,000) tons per year. The average annual sewage load in the U.S. is 8,000,000 tons per year.



In addition to filling up reservoirs, sediment will also block shipping channels. Considering that **46%** of our imported goods come via the water ways, we can see that silt accumulation in our shipping channels may be a major issue.

Figure 21. Dredging our waterways.

The following tables illustrate the cost of sediment removal through dredging in the U.S. (Table 2.6) and in Virginia (Table 2.7) as conducted by the U.S. Army Corps of Engineers. Note that nation-wide removal has been consistently between 0.20 and 0.27 billion cubic yards. These figures do not include the private dredging done by property owners, neighborhood associations, and marinas.

TABLE 2.6. AMOUNT OF SEDIMENT REMOVED BY DREDGING IN THE US AND ASSOCIATED COST FROM 1998 TO 2009 (SOURCE U.S. ARMY CORPS OF ENGINEERS).

Year	Sediment Removed (CY)	Total Cost	Cost per CY
1998	238,780,700	$ 712,572,600	$ 2.98
1999	284,056,000	$ 815,931,900	$ 2.87
2000	285,332,000	$ 821,677,700	$ 2.87
2001	268,468,100	$ 867,758,200	$ 3.23
2002	248,579,800	$ 1,850,096,400	$ 7.44
2003	233,804,500	$ 887,345,900	$ 3.80
2004	265,240,900	$ 903,132,300	$ 3.41
2005	255,079,800	$ 956,490,700	$ 3.75
2006	204,281,000	$ 966,187,600	$ 4.73
2007	206,872,900	$ 996,193,800	$ 4.81
2008	216,450,200	$ 1,011,725,200	$ 4.67
2009	263,625,000	$ 1,344,107,100	$ 5.10

TABLE 2.7. AMOUNT OF SEDIMENT REMOVED BY DREDGING IN VIRGINIA AND ASSOCIATED COST FROM 2004 TO 2009 (SOURCE U.S. ARMY CORPS OF ENGINEERS).

Year	Number of Contracts	Sediment Removed (CY)	Total Cost	Cost per CY
2004	12	5,919,790	$ 27,757,785	$ 4.69
2005	6	2,394,600	$ 9,217,654	$ 3.85
2006	7	2,133,950	$ 10,453,199	$ 4.90
2007	6	3,510,000	$ 26,046,734	$ 7.42
2008	7	1,226,100	$ 8,245,203	$ 6.73
2009	17	2,659,600	$ 18,031,070	$ 6.78

Additional impacts from erosion and sedimentation include:

- The cost to clean-up water for use as drinking water,
- The loss of fertile topsoil with a resulting loss in productivity of the land,
- Sediment deposition on land,
- In-stream erosion (Figure 20 and Module 4),
- Flooding resulting in property damage (Figure 21 and Module 4),
- Increases in turbidity in the water and habitat loss for aquatic organisms.

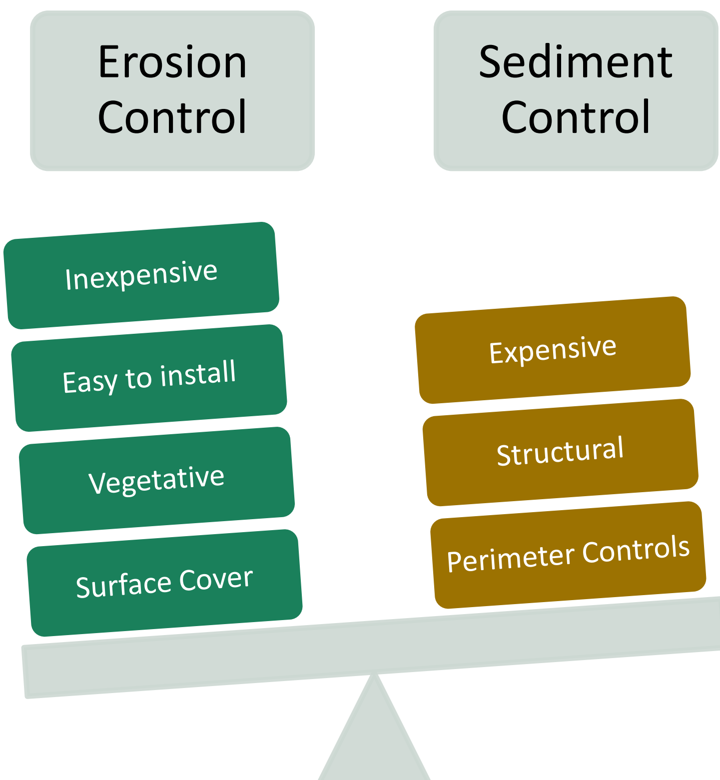
Figure 22. Increased frequency and duration of large flow events and sediment load increases have caused more in-stream erosion and erosion of bed and banks of this stream, resulting in an unstable condition and potential loss in spawning habitat and food supply for any aquatic organisms in this stream including fish.

Figure23. Out-of-Bank Flooding Endangers Human Life and Property
(Source: ARC, 2001)

2g. Main Principles of Erosion and Sediment Control

If we can control erosion we do not need to do sediment control

The Virginia Erosion and Sediment Control Program targets accelerated erosion. More specifically, as the title indicates, it addresses (1) erosion control and (2) sediment control. The order, *erosion* and *sediment* control was chosen for a reason: erosion control is often considered a first line of defense, if we can control erosion we do not need to do sediment control. Sediment control is considered a second line of defense, it catches the sediment from areas where erosion controls could not be installed or where they failed to work properly. Sediment control is always necessary on land disturbance projects since by definition a site can never be completely stabilized when land disturbance takes place. Erosion control is generally less costly that installing sediment control measures, and therefore erosion control generally minimizes the cost of the E&S program on a project. In addition, by trying to minimize erosion we can greatly reduce the number of sediment control measures on a site and minimize the maintenance of sediment control structures, saving additional funds.



2h. Sediment in Stormwater Runoff (a Summary)

Average annual rainfall across Virginia = 42 to 48 inches per year, isolated areas average less than 38 inches or more than 66 inches. All this precipitation is either going to infiltrate, evaporate of run off the land surface. In this section we discussed what the precipitation does and what happens when it runs of development sites or Land Disturbance Areas (LDA).

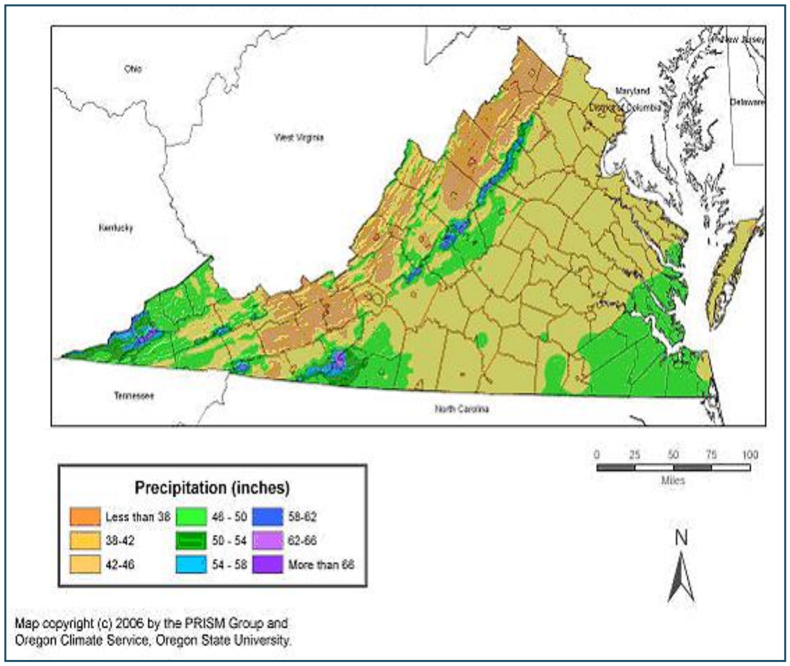
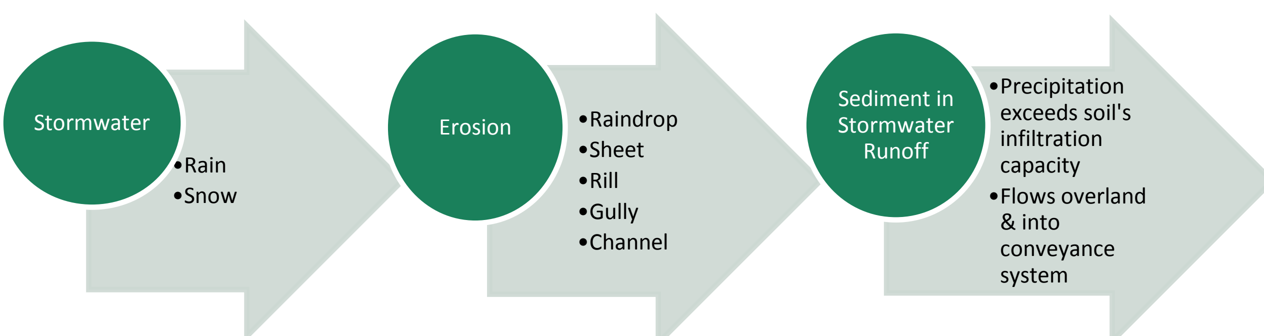


Figure 24. Average Virginia Annual Precipitation, 1970-2000. (Source: Oregon Climate Service)



Knowledge Check

1. **On a per acre basis which NPS contributes the most sediment?**

    a. **Agriculture**
    b. **Mining**
    c. **Construction**
    d. **Forestry**

2. **Which water erosion process accounts for the highest erosion percentage?**

    a. **Rill**
    b. **Raindrops**
    c. **Sheet Flow**
    d. **Gully**

3. **In which month would precipitation intensity have the greatest impact on soil?**

    a. **Oct.**
    b. **May**
    c. **Feb.**
    d. **About the same**

4. **The higher the K factor, the less likely a soil will erode?**

    a. **True**
    b. **False**

5. **Vegetative controls are _______ costly then structural controls?**

    a. **more**
    b. **less**